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**Technology &
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Water/Road Interaction Field Guide

WATER/ROAD INTERACTION TECHNOLOGY SERIES

surface drainage

drainage crossings

subsurface drainage

Water/Road Interaction Field Guide

Water/Road Interaction Core Team

USDA Forest Service

San Dimas Technology and Development Center
San Dimas, California

September 2000

INTRODUCTION

The purpose of the Guide is to:

- Provide an illustrated field-going guide of observable water/road interaction problems damaging to road, watershed condition, water quality, aquatic life, or public safety;
- Increase awareness of how road location, design, maintenance, and management affect interactions with rainfall, runoff, and ground water;
- Facilitate communication on water/road interaction problems among professionals and technicians in a variety of physical and biological science disciplines and fields of engineering;
- Improve recognition of basic road drainage problems, and the ability to identify and verify likely causes;
- Increase awareness of possible alternative treatments to mitigate existing problems;
- Develop knowledge and experience required to conceptualize road segment characteristics that provide desired safe access with minimal affect to watershed, water resources, and aquatic life;
- Help inform line officer decisions.

Many drainage problems on low volume roads begin with surface water concentration and flow. Other problems involve road/stream crossings. Below are some contrasts, illustrated by the guide, between desirable conditions and those in which damage is occurring to road and/or watershed:

- **Desired:** Roadway surfaces are sufficiently drained such that water flows do not concentrate volume or erosive energy levels causing access, safety, maintenance, or environmental problems;

- **Damaging:** Roadway surfaces exhibit water concentration and erosion, with rills or gullys present over substantial areas. Wheel ruts present in the traveled way channel flow. The road prism is entrenched into the landscape;

- **Desired:** Roadway surfaces are sufficiently treated such that concentrated flows do not leave the prism with volume or energy sufficient to cause gullys to adjacent areas or other mass erosion;

- **Damaging:** Adjacent areas exhibit gullys that are not associated with the unroaded landscape condition. Sediment has been deposited in drainage ways and streams downslope of the road;

- **Desired:** Road/stream crossings are designed to adequately duplicate naturally occuring conditions for passage of water, debris, bedload, and aquatic organisms, and do not exhibit diversion potential;

- **Damaging:** Passage of one or more of the required entities is constricted, and diversion potential exists.

An electronic version of the draft Water/Road Interaction Field Guide is available on the San Dimas Technology and Development Center's intranet web page. Navigate to Engineering, then Water/Road. The Field Guide link refers to a "work in progress."

The Water/Road Interaction Field Guide is based on observable water/road interactions in ten major problem areas. These problem areas are:

- Surface water concentration problems on the traveled way;
- Surface water concentration problems on the backslope;
- Surface water concentration problems on the fillslope;
- Ditch or lead out ditch problems;
- Subsurface flow interception by the prism;
- Surface cross drain failure;
- Ditch relief culvert failure;
- Channel impacts/increased drainage density;
- Channel encroachments from road alignment in channel/flood plain;
- Road/Stream crossing problems.

Each of these ten problem areas contain multiple observations illustrated by photos. Each observation also provides:

- Important site/road conditions;
- Some possible treatments;
- A reference/definition aid, and
- A list of disciplines available to help recognize and analyze the problem.

Photos are captioned and show two scenarios: example observations of a water/road interaction problem on the ground, and situations in which the problem could occur, but does not, due to either nature or design. This is referred to in the Guide as Proper Drainage Provision.

Important road/site conditions are included with each observation as an aid to information gathering and to highlight critical conditions. The observer should consult with a specialist in the listed field for more information on critical conditions. Important site/road conditions are described as follows:

- Geology—includes parent material characteristics, soil properties, and slope stability;
- Climate—takes into consideration precipitation amounts, types, durations, intensities, and ambient temperatures;
- Topography—includes landform type, shape, and relief;
- Vegetation—involves types, characteristics, and ease of establishment;
- Biology—includes plant, animal, and fish considerations as affected by road drainage and road drainage structures;
- Template—refers to back and fillslope ratios and heights, traveled way surface shape and width, presence or absence of ditches and berms, and construction methods;
- Grade—road grade;
- Access—includes aspects of road location, road standards, maintenance, and vehicle considerations;

- Policy—refers to any external constraints imposed on transportation system development and activities other than those described above.

Important site/road conditions are included to help the observer gather and organize information needed to recognize and analyze the problem. This list is not exhaustive: other conditions may apply and required information gathering needs can vary considerably.

Possible treatments listed are basic configurations. Many other options and specialized treatments exist to aid solution of water/road interaction problems but are beyond the scope of this guide. The observer should consult with the specialist listed for more information on possible treatments. References (in italics) are mainly related to documents in the Water/Road Interaction Technology Series binder. Basic definitions and a listing of specialties for consultation are also provided. Specialties include hydrology, biology, geology, forestry, engineering, geotechnical engineering, maintenance, and include the Interdisciplinary Team in general.

The Water/Road Interaction Field Guide

Is	Is Not
A mentoring, training, and general design aid for professionals and technicians in physical and biological science and engineering disciplines.	For specific design use by experienced professionals and technicians.
To facilitate use of the Water/Road Interaction Technology Series.	A stand-alone document that is comprehensive in and of itself.
As simple and concise as is reasonably possible.	An expert system.
A problem recognition and analysis tool.	A problem correction tool.
For leading from observations to most likely causes or basic problems.	For jumping from observation to treatment action.
For considering alternative treatments that could feasibly correct observed road drainage problems.	For prescribing a selected treatment.
For facilitating communication and conceptual understanding among personnel.	For selecting a specific course of action.
A field-going guide on low volume road drainage problems.	An office bound reference.
For use within the scope of typical authority of entry level professionals.	To encourage actions beyond typical authority or to bypass the decision making process.

Surface Water
Concentration Problem
on the Traveled Way

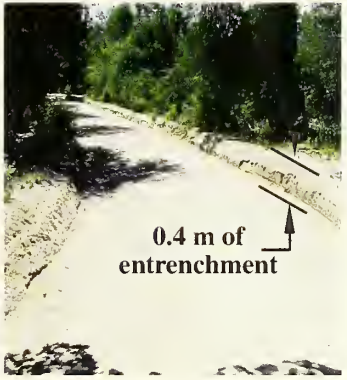
Surface Water Concentration Problems on the Traveled Way

Loss of Surface Materials

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Template Grade	Add surface cross drainage	Engineer, Hydrologist	*The X-DRAIN Cross Drain Spacing and Sediment Yield Model, Cross Drain Update, Introduction to Surface Cross Drains*
	Modify template	Engineer	*Traveled Way Surface Shape*
Access Policy	Harden surface	Engineer	Pave, aggregate, vegetation, or chemical binder.

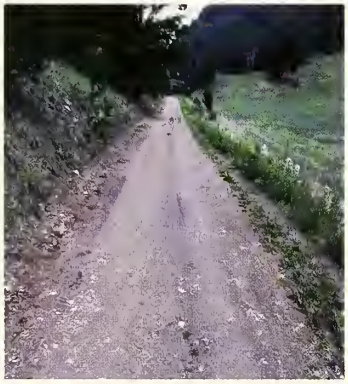
LOSS OF SURFACE MATERIALS

Surface water concentration and erosion on traveled way surface.

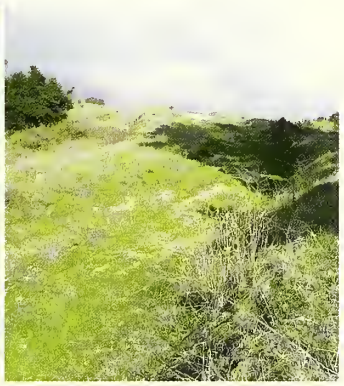


Entrenchment of traveled way surface to 0.4 m below surrounding terrain due to use, erosion, and surface blading.

PROPER DRAINAGE PROVISION



Stable backslopes and fillslopes; well drained road surfaces.



Grass on road surface prevents loss of surface materials.

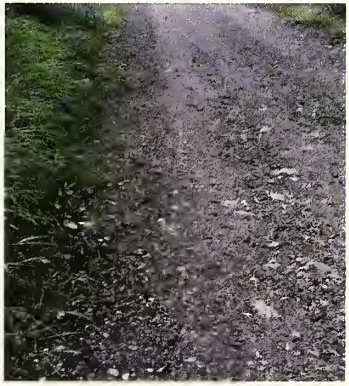
Gullying

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology	Add surface cross drainage	Engineer, Hydrologist	*The X-DRAIN Cross Drain Spacing and Sediment Yield Model, Cross Drain Update, Introduction to Surface Cross Drains*
Climate	Modify template	Engineer	*Traveled Way Surface Shape*
Template	Harden surface	Engineer	Pave, aggregate, or chemical binder.
Grade	Remedial maintenance	Maintenance Foreman	Remove gullies, maintain traveled way surface and other drainage provision to avoid gully erosion.

GULLYING

Gully formation on traveled way due to concentrated surface flow.

PROPER DRAINAGE PROVISION



Stable backslopes and fillslopes; well drained road surfaces.

Rutting

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Template Access Policy	Add surface cross drainage	Engineer	Drain subgrade to ensure bearing capacity for wheel loads.
	Harden surface	Engineer	Pave or apply aggregate.
	Remedial maintenance	Maintenance Foreman	Remove ruts; drain traveled way.
	Manage traffic	Interdisciplinary Team	Seasonal closure; use restrictions.
	Open canopy	Biologist, Engineer, Forester	Remove vegetation; increase drying of traveled surface.

RUTTING

Rutting of traveled way surface due to saturation and wheel loads.

PROPER DRAINAGE PROVISION

Well drained outsloped road resists rutting.

Sedimentation

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Climate Topography Vegetation	Add surface cross drainage, isolate water concentra-tions	Engineer, Hydrologist	*The X-DRAIN Cross Drain Spacing and Sediment Yield Model, Cross Drain Update, Introduction to Surface Cross Drains*
Biology Template	Vegetative treatments, buffers	Biologist, Forester, Range Conservationist	Seeding, mulching, hydromulching, paper mulch, biotechnical treatments.
Grade Access	Remedial maintenance	Maintenance Foreman	Treat eroding surfaces and design drainage provision to avoid gully erosion.

SEDIMENTATION

Sedimentation on traveled way due to material eroded from higher on the road grade.

Surface water concentration on road washes light cinder surfacing through lead out ditch to be deposited in meadow.

Material deposited on traveled way, eroded from upslope on the road, and subsequently removed and piled here during maintenance operations.

PROPER DRAINAGE PROVISION

Grass on road prism prevents loss of surface materials.

Ponding

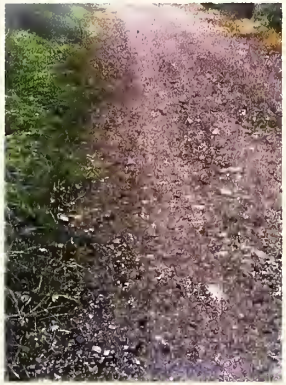
Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Climate Topography Template Grade Access Policy	Direct flow underneath road surface in french drain	Engineer, Hydrologist	French drain, aggregate, and geotextile or geocomposite.
	Direct flow underneath road surface in permeable fill	Engineer, Hydrologist	Large, uniformly graded rocky fill with riding surface cap.
	Install low water crossing	Engineer, Hydrologist	Traveled way designed for overtopping flows.
	Modify template	Engineer	*Traveled Way Surface Shape*

PONDING

Ponding.

Ponding on the traveled way.

PROPER DRAINAGE PROVISION



Stable backslopes and fillslopes, well drained road surfaces.

Porous road fill prevents ponding problems on the traveled way.

Berms

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Climate Topography Vegetation Template Access Policy	Remove berm	Engineer, Hydrologist	*Traveled Way Surface Shape*
	Excavate drainage path through berm	Engineer, Hydrologist	Outslope and provide drainage path or lead out ditch for surface flow over downhill shoulder.
	Adjust snow removal practices	Engineer, Hydrologist	Ensure snow removal practices do not result in berms or surface water concentration on the road prism.

BERMS

Large berm increases distributed width of road and acts to keep water channeled on traveled way.

Insloped traveled way with large berm on outside shoulder. Note the existence of rills running perpendicular to road center line even after surface blading.

Berm left during snow plowing can lead to surface water concentration on the traveled way.

PROPER DRAINAGE PROVISION

Berm removal allows surface flow over downhill shoulder.

Surface Water
Concentration Problems
on the Backslope

Surface Water Concentration Problems on the Backslope

Erosion

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template	Vegetation, increase cover	Biologist, Forester, Engr, Range Conservationist	Seeding, mulch, hydromulch, papermulch, geosynthetic, biotechnical.
	Modify slope	Engineer	Reduce slope, serrate, bench.
	Harden surface	Engineer	Rock rip-rap, check dams.
	Dispurse flow from above backslope	Engineer, Hydrologist, Forester	Ditch and/or berm.

EROSION

Backslope erosion and deposition of material on traveled way.

Surface water concentration from above causing erosion of backslope: attempt to harden slope.

PROPER DRAINAGE PROVISION

Erosion susceptable backslope armored with rock rip-rap.

Rolled hay bales placed at intervals on the backslope to reduce water concentrations and erosion.

Slides on Backslope (Instability)

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Access Policy	Modify slope, template	Geotechnical Engineer	Reduce slope, bench, retaining walls.
	Modify weight distribution	Geotechnical Engineer	Rock buttress.
	Bioengineer-ing	Engineer, Biologist	Mechanical plus vegetative treatments.

SLIDES ON THE BACKSLOPE

Slumping backslope failure.

Slumping failure on the backslope.

PROPER DRAINAGE PROVISION

Stable, well vegetated backslope.

Rock filled gabion basket protection on backslope.

Slides Extending Above Backslope

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Access Policy	Consultation	Geotechnical Specialist	N/A

SLIDES EXTENDING ABOVE BACKSLOPE

Material above top of cut slope available for transport down to traveled way surface.

Material deposited on traveled way from a slide extending above the top of cut.

Hillslope above backslope sliding onto traveled way surface.

PROPER DRAINAGE PROVISION

Stable, well vegetated backslope.

Surface Water
Concentration Problems
on the Fillslope

Surface Water Concentration Problems on the Fillslope

Erosion

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Grade	Divert or disperse flow from upslope template, areas	Engineer, Hydrologist	*Traveled Way Surface Shape, Introduction to Surface Cross Drains, the X-DRAIN Cross Drain Spacing and Sediment Yield Model*
	Establish vegetation	Biologist, Forester, Range Conservationist	Seed, mulch, plantings, biotechnical.
	Armor surface	Engineer	Rock rip-rap, geosynthetics.
	Adjust snow removal practices	Engineer, Mtnc. Foreman	Ensure practices do not lead to surface water concentrations.
	Add over-side drains	Engineer	Drainage structure that protects fillslope from erosion. Caution: can increase erosive energy of water flow.

EROSION

Surface water concentration on fillslope from grade dip out-flow.

Erosion of fillslope due to concentrated surface flow.

PROPER DRAINAGE PROVISION

Rock rip-rap protection on the fillslope.

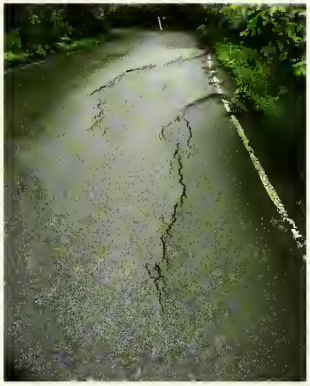
Stable, well vegetated fillslope.

Tension Cracks

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Grade Access Policy	Consultation	Geotechnical Specialist	N/A

TENSION CRACKS

Tension crack in traveled way due to excessive weight of saturated embankment.



Tension cracks in asphalt surface due to embankment settlement.

PROPER DRAINAGE PROVISION

Well drained outslope road resists tension cracking.

Slides

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Grade Access Policy	Consultation	Geotechnical Specialist	N/A

SLIDES

Over steepened fillslope slide.

PROPER DRAINAGE PROVISION

Grouted rock retaining wall to stabilize fillslope.

Precast concrete log crib structure to stabilize fillslope.

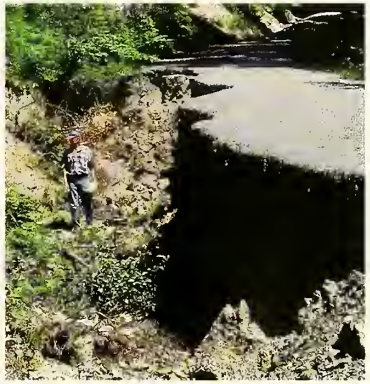
Ditch or Lead Out
Ditch Problems

Ditch
or Lead Out
Ditch Problems

Erosion

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Grade	Increase ditch relief	Engineer, Hydrologist, Biologist	*Relief Culverts*
	Decrease flow contribution from traveled way	Engineer, Hydrologist	*Traveled Way Surface Shape*
	Decrease flow contribution from backslope	Engineer, Hydrologist	Vegetation, biotechnical, or mechanical treatments to backslope.
	Vegetation	Biologist, Range Conservationist	Seed with grasses suitable for ditch.
	Harden or armor flow area	Engineer	Line ditch with rock rip-rap or aggregate, or use in ditch culvert.
	Modify ditch geometry	Engineer	Widen and flatten flow path if possible, or add energy dissipators.

EROSION



Erosion and downcutting of inboard ditch.

PROPER DRAINAGE PROVISION

Ditch pavement to resist erosion and subsequent sedimentation.

Grouted rock lead out ditch resists erosion.

Sedimentation

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Template Grade Access Policy	Reduce upslope erosion	Engineer, Hydrologist, Biologist	Harden, vegetate upslope area.
	Decrease flow contribution from traveled way	Engineer, Hydrologist	*Traveled Way Surface Shape*
	Decrease flow contribution from backslope	Engineer, Hydrologist	Vegetation, geosynthetic or organic mat, structural treatments.
	Modify ditch geometry, relief	Engineer, Hydrologist	Steepen flow path if possible.

SEDIMENTATION

Clogging of ditch with sediment from upslope road segment.

Deposition, clogging of lead out ditch with light cinder surfacing washed from traveled way.

PROPER DRAINAGE PROVISION

Properly functioning lead out ditch.

Well vegetated ditch reduces downstream sedimentation.

Backslope Undermining

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Grade Policy	Harden ditch, in-ditch culvert	Engineer	Pave, line with rock, vegetate. In-ditch culvert prevents downcutting.
	Modify ditch geometry	Engineer	Flatten flow path if possible.

BACKSLOPE UNDERMINING

Undermining of backslope due to downcutting of ditch.

PROPER DRAINAGE PROVISION

Paved ditch resists erosion and downcutting.

Well vegetated ditch reduces backslope undermining.


Subsurface Flow
Interception
by the Prism

Subsurface Flow Interception by the Prism

Prism Saturation

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Template Access Policy	Direct flow underneath road surface in french drain	Engineer, Hydrologist	French drain, aggregate, and geotextile or geocomposite.
	Direct flow underneath road surface in porous fill	Engineer, Hydrologist	Large, uniformly graded rocky fill with riding surface cap.
	Seal or harden riding surface	Engineer	Pavement, aggregate.
	Install low water crossing	Engineer, Hydrologist	Subgrade designed to support wheel loads and survive overtopping flows.

PRISM SATURATION

Backslope seepage causing saturated road subgrade.

PROPER DRAINAGE PROVISION

View of porous fill built over area saturated by exfiltration of subsurface flow.

Porous fill prevents prism saturation problems due to intercepted subsurface flow.

Erosion/Rutting

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Template Grade Access Policy	Direct flow underneath road surface in french drain	Engineer, Hydrologist	French drain, aggregate, and geotextile or geocomposite.
	Direct flow underneath road surface in porous fill	Engineer, Hydrologist	Large, uniformly graded rocky fill with riding surface cap.
	Harden riding surface	Engineer	Pavement, aggregate.
	Install low water crossing	Engineer, Hydrologist	Traveled way designed for overtopping flows.

EROSION/RUTTING

Erosion and rutting potential due to subsurface flow interception by the prism.

PROPER DRAINAGE PROVISION

Porous fill provides hardened riding surface to resist erosion and rutting.

Ponding

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography	Add surface cross drainage	Engineer	*Cross Drain Update*
Template Grade Access	Modify template	Engineer	*Traveled Way Surface Shape*

PONDING

Ponding problems due to subsurface flow interception by the prism.

Ponding problem on traveled way due to intercepted subsurface flow.

PROPER DRAINAGE PROVISION

Built-up porous fill relieves ponding problems by providing drainage in areas exhibiting exfiltration of subsurface flow.

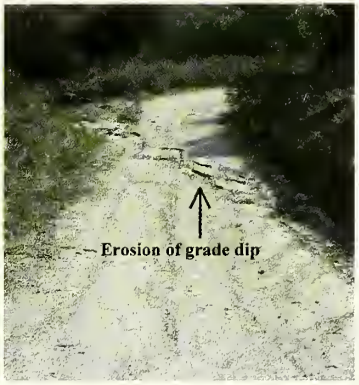
Surface
Cross Drain
Failure

Surface Cross Drain Failure

Erosion of Cross Drain

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Template Grade Access	Add surface cross drainage	Engineer, Hydrologist	*The X-DRAIN Cross Drain Spacing and Sediment Yield Model, Cross Drain Update, Introduction to Surface Cross Drains*
	Minimize contributing drainage areas	Engineer, Hydrologist	Reduce area contributing surface flow with vegetation, organic material, or geosynthetics.
	Isolate contributing drainage areas	Engineer, Geologist	Keep surface flows from individual contributing areas from accumulating.
	Clean/maintain/ restore cross drain	Maintenance Foreman	Restore cross drain function.
	Harden drain area	Engineer	Provide erosion proof or resistant flow path.
	Vegetation	Biologist, Forester, Range Conservationist	Seed, mulch, or plantings.

EROSION OF CROSS DRAIN



Erosion of grade dip.

PROPER DRAINAGE PROVISION

Grouted rock lead out ditch resists erosion.

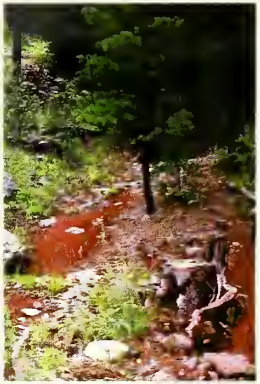
Uniformly graded rock used to armor cross drain.

Deposition

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template	Add surface cross drainage	Engineer, Hydrologist	*The X-DRAIN Cross Drain Spacing and Sediment Yield Model, Cross Drain Update, Introduction to Surface Cross Drains*
	Clean/maintain/ restore cross drain	Maintenance Foreman	Restore cross drain function.
Grade Access	Harden/armor upslope surface	Engineer, Geologist	Reduce erosion from upslope areas to reduce downstream deposition.

DEPOSITION

Filling in of grade dip outflow with sediment.



Deposition of light cinder road surfacing in meadow and clogging of lead out ditch.

PROPER DRAINAGE PROVISION

Hardened upslope surface resists erosion, allowing this grade dip outflow to remain free flowing.

Bypassed Structure

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Grade Access	Add surface cross drainage	Engineer, Hydrologist	*The X-DRAIN Cross Drain Spacing and Sediment Yield Model, Cross Drain Update, Introduction to Surface Cross Drains*
	Deepen drainage structure (consult engineer)	Engineer	Ensure flow paths are directed into cross drain.

BYPASSED STRUCTURE

Bypassing of cross drain outflow due to deposition of sediment.

Bypassed lead out ditch due to insloped traveled way surface shape.

PROPER DRAINAGE PROVISION

Lack of bypass problems on lead out ditch.

Ditch Relief
Culvert Failure

Ditch
Relief
Culvert
Failure

Inlet Plugging

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Grade Access	Remove inlet obstructions	Maintenance Foreman	Clean inlet, trash rack, or sedimentation pond.
	Vegetate upslope area	Biologist, Forester, Range Conservationist	Seed or plant upslope area to reduce erosion.
	Diversion prevention dip	Engineer, Hydrologist	*Diversion Potential at Road/Stream Crossings*
	Maintain/clean ditch	Maintenance Foreman	Remove materials threatening inlet plugging.
	Gully treatments	Engineer, Hydrologist, Geologist	Gully plugs or harden ditch.
	Entrance treatments	Engineer	Enhance passage of debris.

INLET PLUGGING

Ditch relief culvert subject to sediment plugging.

Ditch relief culvert on the verge of plugging due to sedimentation in inlet basin.

PROPER DRAINAGE PROVISION

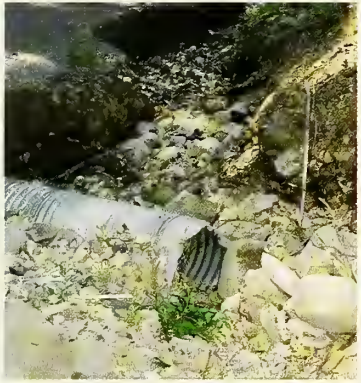
Cast in place concrete catch basin creates swirling action that flushes organic debris and sediment through cross drain culvert.

Ditch relief culvert inlet plugging prevented by concrete "L" shaped structure.

Inlet Bypassing

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template Grade Access	Ditch dam	Engineer, Hydrologist	Dam ditch to direct flow into culvert.
	Maintain/ clean ditch	Maintenance Foreman	Remove materials threatening inlet plugging and subsequent bypassing.
	Modify template	Engineer	Ensure template directs flow into culvert.
	Diversion prevention dip	Engineer, Hydrologist	*Diversion Potential at Road/Stream Crossings*

INLET BYPASSING



Ditch erosion down-stream of bypassed ditch relief culvert inlet.

Bypassed cross drain culvert due to complete burial under sediment.

PROPER DRAINAGE PROVISION

Cast in place concrete catch basin functions as a ditch dam to prevent inlet bypassing.

Ditch relief culvert inlet bypassing pre-vented by concrete "L" shaped structure.

Corroded or Damaged Pipe

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Policy	Replace/ realign/move culvert (consult engineer)	Engineer	Grout or pave corroded invert; repair or replace pipe damaged by maintenance operations.

CORRODED OR DAMAGED PIPE

Cross drain pipe inlet dented during maintenance operation contributes to deposition in inlet basin.

Ditch relief culvert failure due to crushed pipe inlet.

PROPER DRAINAGE PROVISION

Concrete cross drain pipe resists corrosion and damage.

Instability Below the Outlet

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Template	Replace/ realign/move culvert	Engineer	Consult Engineer.
	Construct retaining wall	Geotechnical Engineer	Prop unstable slope.
	Outlet downspout	Engineer, Hydrologist	Protect unstable area.

INSTABILITY BELOW THE OUTLET

Ditch relief culvert outlet "shotgunned" due to fillslope erosion and instability.

PROPER DRAINAGE PROVISION

Rock retaining wall to increase stability of fill over ditch relief culvert.

Member of a set of closely spaced ditch relief culverts minimizes affects to surroundings.

Outlet Scour

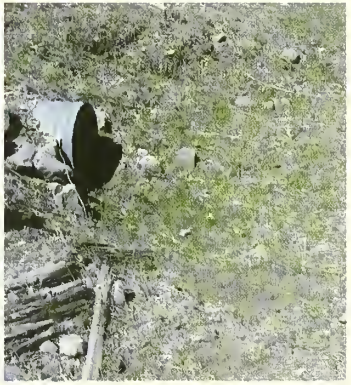
Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation	Harden outfall	Engineer	Rock rip-rap or outlet downspout to protect receiving area.
	Add ditch relief	Engineer, Hydrologist	Reduce flow onto unstable area.
	Replace/ realign/move culvert (consult engineer)	Engineer	Move pipe so outflow is onto stable area.

OUTLET SCOUR

Scour at ditch relief culvert outlet.

PROPER DRAINAGE PROVISION

Dry laid rock masonry with sill built by CCC reduces outlet scour.



Member of a set of closely spaced ditch relief culverts minimizes affects to surroundings.

Inadequate Pipe Cover

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Template Access	Ramp over pipe	Engineer, Hydrologist	Place additional material over pipe installation.
	Reduce loss of fines/erosion over pipe	Maintenance Foreman	Properly maintain roadbed to reduce erosion.

INADEQUATE PIPE COVER

Inadequate cover over pipe.

Inadequate cover over corrugated metal pipe approximately 0.15m (6 in) deep where 0.3m (12 in) is required.

Inadequate cover over pipe.

PROPER DRAINAGE PROVISION

Ample cover on ditch relief culvert.

Channel Impacts/
Increased Drainage
Density

Channel Impacts/
Increased
Drainage
Density

Erosion

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Template Grade Access	Slow and disperse water flows	Engineer, Hydrologist	*Traveled Way Surface Shape, The X-DRAIN Cross-Drain Spacing and Sediment Yield Model, Introduction to Surface Cross Drains*
	Vegetation	Biologist, Forester, Range Conservationist	Vegetate eroding areas.
	Gully treatments	Engineer, Hydrologist, Geologist	Use vegetative and/or mechanical treatments to reduce gully erosion.
	Diversion prevention dip	Engineer, Hydrologist	*Diversion Potential at Road-Stream Crossings*
	Reduce contributing area	Engineer, Hydrologist	*Traveled Way Surface Shape, The X-DRAIN Cross-Drain Spacing and Sediment Yield Model, Introduction to Surface Cross Drains*

EROSION

Gully erosion resulting in increased drainage density due to excess surface water concentration from traveled way.

PROPER DRAINAGE PROVISION

Elevated CMP inlet/elbow encourages ponding, deposition, and soil moisture recharge, while buffering downstream flows and reducing erosion.

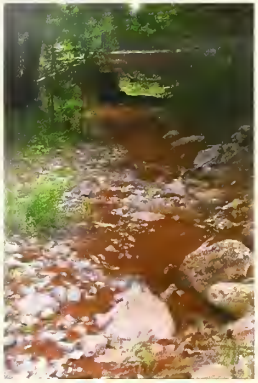
Successful seeding and revegetation reduces erosion and channel development upstream of a road drainage structure.

Sedimentation

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Template Grade Access Policy	Vegetation	Biologist, Forester, Range Conservationist	Use vegetation to reduce sediment transport.
	Gully treatments	Engineer, Hydrologist, Geologist	Use gully plugs to increase deposition in desired locations.
	Sedimentation ponds	Engineer, Hydrologist, Biologist	Use sedimentation ponds to increase deposition in desired locations.

SEDIMENTATION

Deposition upstream of road stream crossing due to inadequate pipe capacity.



Channel bottom clogged with light cinder surfacing from road.

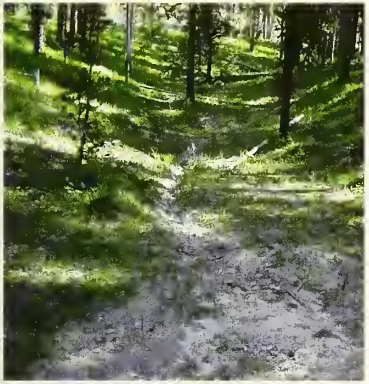
PROPER DRAINAGE PROVISION

Sedimentation pond causes deposition in desired location and protects downstream areas.

Hydrologic Connectivity

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Template	Slow and disperse water flows	Engineer, Hydrologist	*Traveled Way Surface Shape, The X-DRAIN Cross-Drain Spacing and Sediment Yield Model, Introduction to Surface Cross Drains*
	Vegetation	Biologist, Forester, Range Conservationist	Use vegetation to slow flows and stabilize soil.
	Desynchronize flows	Engineer, Hydrologist	*Traveled Way Surface Shape, The X-DRAIN Cross-Drain Spacing and Sediment Yield Model, Introduction to Surface Cross Drains*
	Reduce contributing area	Engineer, Hydrologist	*Traveled Way Surface Shape, The X-DRAIN Cross-Drain Spacing and Sediment Yield Model, Introduction to Surface Cross Drains*
	Gully treatments	Engineer, Hydrologist	Treat gullies with plugs, vegetation, biotechnical, mechanical methods.

HYDROLOGIC CONNECTIVITY



Hydrologic connectivity between road and stream due to surface water concentration and flow off road.

PROPER DRAINAGE PROVISION

Gullying in area adjacent to road due to hydrologic connectivity successfully treated, with area healing.

Reduced Moisture

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Template	Slow and disperse water flows	Engineer, Hydrologist	*Traveled Way Surface Shape, The X-DRAIN Cross-Drain Spacing and Sediment Yield Model, Introduction to Surface Cross Drains*
	Vegetation	Biologist, Forester, Range Conservationist	Use of vegetation to increase soil moisture recharge.
Grade Access	Retain moisture on site	Engineer, Hydrologist	Perform treatments to reduce loss of moisture from site.

REDUCED MOISTURE

Site drying and groundwater table lowered due to gullies caused by pipes installed below meadow elevation.

PROPER DRAINAGE PROVISION

Proper drainage provision built and maintained into road encourages ponding and recharge of soil moisture.


Channel Encroachment
from Road Alignment
in Channel/ Flood Plain

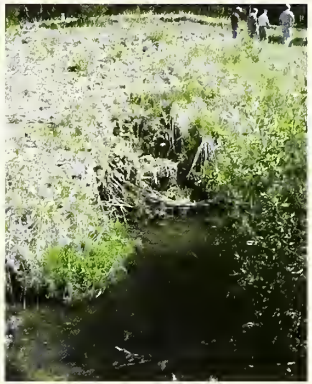
Channel Encroachment from Road Alignment in Channel/Flood Plain

Loss of Road Prism

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Template Grade Access Policy	Realign road	Inter-disciplinary Team	Move road away from stream.
	Install retaining structure	Geotechnical Engineer	Retain and protect fill from erosion.
	Harden fillslope	Engineer	Protect fill from washout.
	Realign stream	Inter-disciplinary Team	Move stream away from road.
	Barbs/ revetments (consultation)	Engineer, Hydrologist, Biologist	Reduce erosion, encourage deposition.

LOSS OF ROAD PRISM

Erosion of the fillslope due to channel encroachment by the road prism.



Erosion of road prism from channel encroachment.

PROPER DRAINAGE PROVISION

Fillslope retaining wall prevents channel encroachment.

Bank barbs placed in channel prevent erosion and encourage deposition, protecting the road prism.

Channel Erosion

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology	Realign road	Inter-disciplinary Team	Move road away from stream.
	Protect channel banks (bioengineer-ing)	Engineer, Hydrologist, Biologist	Vegetative and structural protection.
	In-channel structure	Engineer, Hydrologist	Reduce erosion, encourage deposition.

CHANNEL EROSION

Channel erosion downstream of road/stream crossing structure.

Channel bank erosion worsened by road prism encroachment in channel.

PROPER DRAINAGE PROVISION

Sufficient buffer between road and stream to prevent impacts to stream and fish habitat.

Sedimentation

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation	Consult Biologist	Biologist, Hydrologist	N/A
Biology	Barbs/ revetments (consultation)	Engineer, Biologist	Encourage deposition in desired areas.

SEDIMENTATION

Material eroded from top of fill ends up in stream and degrades fish habitat.

Deposition of light cinder surfacing in channel downslope of road alignment encroaching in channel.

PROPER DRAINAGE PROVISION

Sufficient buffer between road and stream to prevent impacts to stream and fish habitat.

Channel Encroachment

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Access Policy	Realign road	Inter-disciplinary Team	Move road away from stream.
	Realign stream	Inter-disciplinary Team	Move stream away from road.

CHANNEL ENCROACHMENT

Channel encroachment by road prism fillslope.

PROPER DRAINAGE PROVISION

Sufficient buffer between road and stream to prevent impacts to stream and fish habitat.

Over Steepened Stream Channels

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Access Policy	Realign road	Inter-disciplinary Team	Move road away from stream.
	Realign stream	Inter-disciplinary Team	Move stream away from road.
	Barbs/ revetments (consultation)	Engineer, Hydrologist, Biologist, Geologist	Reduce erosion, encourage deposition.
	In channel structure	Engineer, Hydrologist, Biologist	Reduce erosion, encourage deposition.

OVER STEEPENED STREAM CHANNELS

Stream channel steepened, straightened, and shortened due to channel encroaching fill.

PROPER DRAINAGE PROVISION

Sufficient buffer between road and stream to prevent impacts to stream and fish habitat.

Isolation of Flood Plain From Stream

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Climate Topography Biology Access Policy	Realign road	Inter-disciplinary Team	Move road out of flood plain.
	Realign stream	Inter-disciplinary Team	Move stream away from road.

ISOLATION OF FLOOD PLAIN FROM STREAM

View looking away from road at flood plain isolated by turnpike road prism.

Turnpike road fill causing isolation of flood plain.

PROPER DRAINAGE PROVISION

Sufficient buffer between road and stream to prevent impacts to stream and fish habitat.

Road/Stream
Crossing Problems

Road/Stream Crossing Problems

Inlet Plugging

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Vegetation Biology	Remove organic debris	Maintenance Foreman	Clean channel and upslope areas of debris.
	Shape, maintain, clean entrance	Maintenance Foreman, Engineer	Unplug inlet, shape entrance to optimize drainage.
	Trash rack, debris rack	Engineer	Install rack to prevent plugging of inlet by debris.
	Stand pipe w/ drop inlet	Engineer, Hydrologist, Biologist	Stand pipe with drop inlet provides overflow protection in case structure inlet becomes plugged with debris.

INLET PLUGGING

Road stream crossing culverts plugged with debris, leading to scour of the fillslope.

Inlet is partially plugged by rock and is dented by maintenance equipment.

PROPER DRAINAGE PROVISION

Stand pipe with drop inlet overflow protection in debris laden stream.

Removable grid on cast in place culvert provides easy cleaning of debris from drainage crossing structure.

Enlarged Inlet Basin

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Template Policy	Shape/ maintain/ clean basin	Maintenance Foreman	Ensure basin geometry provides for passage of debris through structure.
	Entrance treatment	Engineer	Flared inlet enhances passage of debris.
	Trash or debris rack	Engineer	Trash or debris rack keeps debris from plugging inlet.
	Add drainage structure	Engineer	Added drainage structure provides overflow in case inlet becomes plugged.
	Stand pipe with drop inlet	Engineer	Stand pipe with drop inlet provides overflow in case inlet becomes plugged.

ENLARGED INLET BASIN

Large, open inlet basin encourages blockage of pipe inlet with debris.

PROPER DRAINAGE PROVISION

Tapered inlet basin enhances passage of bedload and woody debris.

Stream Diversion

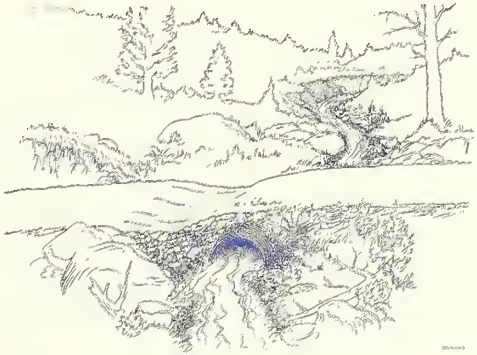
Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology Template Grade Access	Diversion prevention dip	Hydrologist, Engineer	*Diversion Potential at Road-Stream Crossings*

STREAM DIVERSION

Potential stream diversion out of natural channel due to plugging and dented inlet.

PROPER DRAINAGE PROVISION

Absence of stream diversion potential at road stream crossing drainage structure.



Construction of a dip to intercept overtopping flows and prevent diversion down the road or ditchline. This sketch depicts a diversion prevention dip on a low volume, low speed, single-lane road. The dip should intercept any ditchline present, and be of sufficient capacity to handle the entire expected design peakflow. Special care should be exercised in constructing the beginning (upslope end) of the dip where the rediversion of streamflow back toward the channel must occur and persist.

Culvert Washout

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Topography Biology Template	Harden Crossing	Engineer, Hydrologist	Provide erosion resistance to road stream crossing.
	Increase flow capacity	Engineer, Hydrologist	Replace culvert with structure having greater capacity, add culvert, or install an entrance treatment to increase capacity.

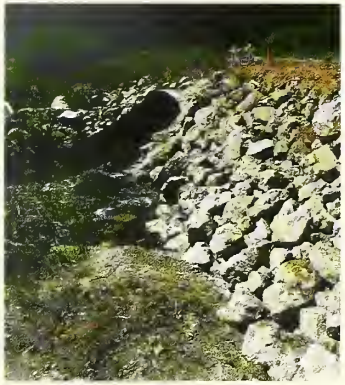
CULVERT WASHOUT

Road stream crossing culvert washout due to insufficient capacity.

Road stream crossing culvert washout due to lack of capacity.

PROPER DRAINAGE PROVISION

Vented low water crossing with concrete pipe and fillslopes.



Road/stream crossing fillslope armored with rip-rap to resist culvert washout.

Culvert Piping

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Biology Template	Entrance treatment	Engineer, Hydrologist	Flared inlet can reduce or eliminate piping.
	Rebed pipe	Engineer	Remove and reinstall pipe using proper bedding materials and procedures.

CULVERT PIPING

Streamflow piping around culvert can lead to embankment failure.

PROPER DRAINAGE PROVISION

Properly bedded pipe prevents piping.

Corroded or Damaged Structures

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Biology Template	Replace pipe	Engineer	Remove damaged structure and install appropriate replacement.
	Repair pipe	Engineer	Use cement grout or insert to extend life of damaged structure.

CORRODED OR DAMAGED STRUCTURES

Rusted pipe inverts cause piping and undermining of structure.

PROPER DRAINAGE PROVISION

Cemented grout repair of abraded and corroded CMP invert.

Excessive Outlet Falls

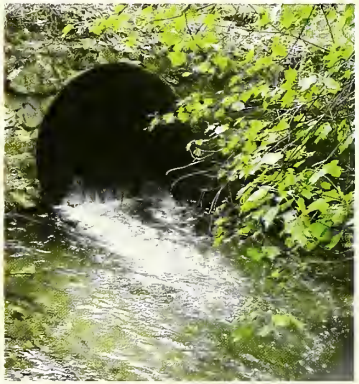
Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Biology	Gully treatments	Hydrologist, Engineer, Biologist, Geologist	Install gully plugs or other treatments to prevent downcutting and encourage deposition.

EXCESSIVE OUTLET FALLS

Channel erosion downstream of road/stream crossing structure.

PROPER DRAINAGE PROVISION

Outlet half pipe to protect fillslope from erosion. Caution: this treatment can accelerate flow and increase downsteam erosion potential.



Ponded condition at road stream crossing drainage structure outlet reduces erosion potential.

Outlet Fillslope Erosion

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Geology Climate Topography Vegetation Biology	Harden fillslope	Engineer	Gabions, cribs, retaining walls, concrete, pavement, or drainage structure extension.
	Rebed pipe	Engineer	Remove and reinstall pipe at proper elevation using proper bedding materials and procedures.
	Gully treatments	Engineer, Hydrologist, Biologist, Geologist	Install gully plugs or other treatments to prevent downcutting and encourage deposition.

OUTLET FILLSLOPE EROSION

Low water crossing with scour and erosion of downstream side.

PROPER DRAINAGE PROVISION

Outlet half pipe to protect fillslope from erosion. Caution: this treatment can accelerate flow and increase downstream erosion potential.

Road stream crossing culvert extending down fillslope to prevent erosion. Caution: this treatment can accelerate flow and increase downstream erosion potential.

Fish Passage Barriers

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Climate Topography Biology	Rebed or replace pipe	Engineer, Biologist	Remove and reinstall pipe using proper bedding materials and procedures at proper inlet and outlet elevations.
	Install fish passage structures	Engineer, Biologist	Baffles or fish ladders.

FISH PASSAGE BARRIERS

Water velocity causes road-stream crossing drainage structure to act as an aquatic species passage barrier.

Channel erosion downstream of road/stream crossing structure presents barrier to aquatic species passage.

PROPER DRAINAGE PROVISION

Fish ladder.

Baffles in road stream crossing drainage structure encourage fish passage.

Inadequate Capacity

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Climate Template	Add drainage structure	Engineer	Increase flow capacity of crossing by additional structure.
	Resize pipe	Engineer	Replace structure with larger capacity structure.
	Entrance treatment	Engineer	Increase capacity by installing flared inlet.

INADEQUATE CAPACITY

Deposition upstream of road stream crossing due to inadequate pipe capacity.

Road/stream crossing drainage structure increasing velocity of stream flow.

PROPER DRAINAGE PROVISION

Road stream crossing drainage structure sized to pass 100-year flow.

Drainage structures (2-24 inch CMP) added to increase crossing capacity.

Improper Alignment

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Climate Topography Biology Template Grade	Realign pipe	Hydrologist, Engineer	Remove and reinstall pipe at proper alignment.

IMPROPER ALIGNMENT

Improper alignment of road stream crossing CMP lead to debris blockage problems.

PROPER DRAINAGE PROVISION

Proper alignment of road stream crossing drainage structure.

Inlet Fillslope Erosion

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Template Grade Access	Fillslope treatments	Engineer	Install gabions, cribs, retaining walls, to reduce or eliminate fillslope erosion.

INLET FILLSLOPE EROSION

Erosion of fillslope.

PROPER DRAINAGE PROVISION

Rock filled gabion inlet fillslope protection.

Increased Hydraulic Energy

Important Site/Road Conditions	Possible Treatments	Specialist	Reference/Definition
Climate Topography Biology Template	Slow and disperse water flows	Engineer, Hydrologist	*Traveled Way Surface Shape, The X-DRAIN Cross Drain Spacing and Sediment Yield Model, Introduction to Surface Cross Drains*
	Vegetation	Biologist, Forester, Range Conservationist	Use vegetation to slow flows.
	Desynchronize flows	Engineer, Hydrologist	*Traveled Way Surface Shape, The X-DRAIN Cross Drain Spacing and Sediment Yield Model, Introduction to Surface Cross Drains*
	Reduce contributing area	Engineer, Hydrologist	*Traveled Way Surface Shape, The X-DRAIN Cross Drain Spacing and Sediment Yield Model, Introduction to Surface Cross Drains*

INCREASED HYDRAULIC ENERGY

Road/stream crossing drainage structure increasing velocity of stream flow.

PROPER DRAINAGE PROVISION

Elevated CMP inlet ponds water and reduces hydraulic energy of flows.

Successful seeding and revegetation of eroded area downstream of a road drainage structure reduces hydraulic energy of flows.